



US010218964B2

(12) **United States Patent**  
**Laffargue et al.**

(10) **Patent No.:** **US 10,218,964 B2**

(45) **Date of Patent:** **\*Feb. 26, 2019**

(54) **DIMENSIONING SYSTEM WITH FEEDBACK**

2207/10024 (2013.01); G06T 2207/10028 (2013.01); H04N 2013/0077 (2013.01)

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(58) **Field of Classification Search**  
CPC ..... G01B 11/024; G06T 17/20; G06T 7/602; G06K 9/036; H04N 13/0271

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USPC ..... 235/472.01  
See application file for complete search history.

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(\* ) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

This patent is subject to a terminal disclaimer.

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(21) Appl. No.: **15/810,719**

(22) Filed: **Nov. 13, 2017**

(65) **Prior Publication Data**

US 2018/0146187 A1 May 24, 2018

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Office Action in counterpart European Application No. 131860439 dated Sep. 30, 2015, pp. 1-7.

(Continued)

**Related U.S. Application Data**

(63) Continuation of application No. 15/581,572, filed on Apr. 28, 2017, now Pat. No. 9,826,220, which is a (Continued)

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(51) **Int. Cl.**

**G01B 11/02** (2006.01)  
**G06T 17/20** (2006.01)

(Continued)

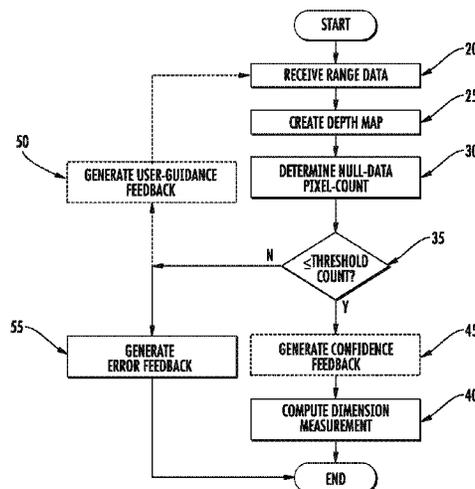
(57) **ABSTRACT**

A dimensioning system that analyzes a distance map for null-data pixels to provide feedback is disclosed. Null-data pixels correspond to missing range data and having too many in a distance map may lead to dimensioning errors. Providing feedback based on the number of null-data pixels helps a user understand and adapt to different dimensioning conditions, promotes accuracy, and facilitates handheld applications.

(52) **U.S. Cl.**

CPC ..... **H04N 13/271** (2018.05); **G01B 11/024** (2013.01); **G01B 11/25** (2013.01); **G06K 9/00201** (2013.01); **G06K 9/036** (2013.01); **G06K 9/22** (2013.01); **G06T 7/62** (2017.01); **G06T 17/20** (2013.01); **H04N 5/23293** (2013.01); **H04N 13/257** (2018.05); **G06T**

**20 Claims, 4 Drawing Sheets**



**Related U.S. Application Data**

continuation of application No. 14/519,195, filed on  
Oct. 21, 2014, now Pat. No. 9,752,864.

**(51) Int. Cl.**

**G06K 9/03** (2006.01)  
**G06T 7/60** (2017.01)  
**H04N 13/02** (2006.01)  
**H04N 13/271** (2018.01)  
**G06K 9/22** (2006.01)  
**H04N 5/232** (2006.01)  
**H04N 13/257** (2018.01)  
**G06K 9/00** (2006.01)  
**G06T 7/62** (2017.01)  
**G01B 11/25** (2006.01)  
**H04N 13/00** (2018.01)

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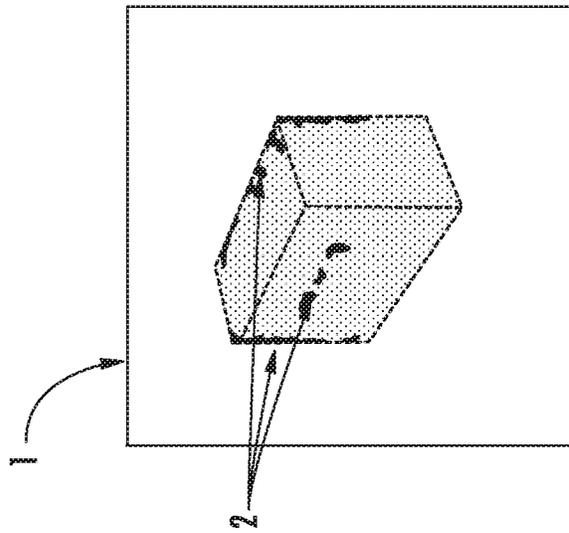


FIG. 1

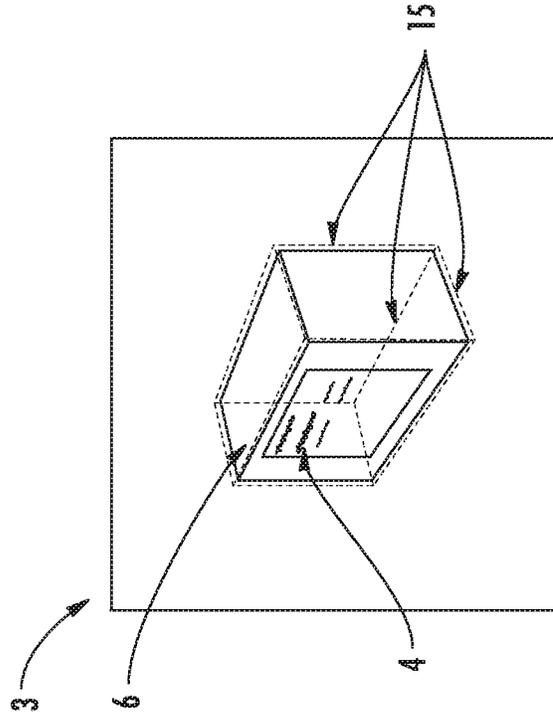


FIG. 2

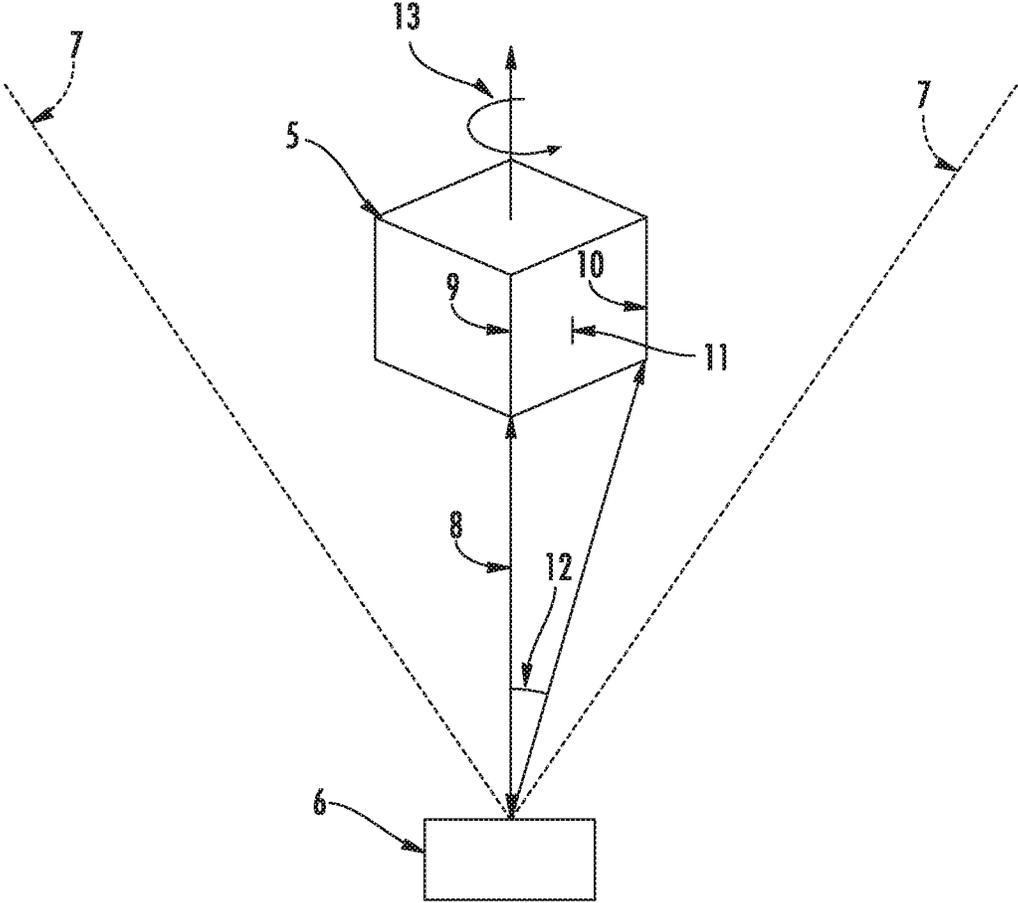


FIG. 3

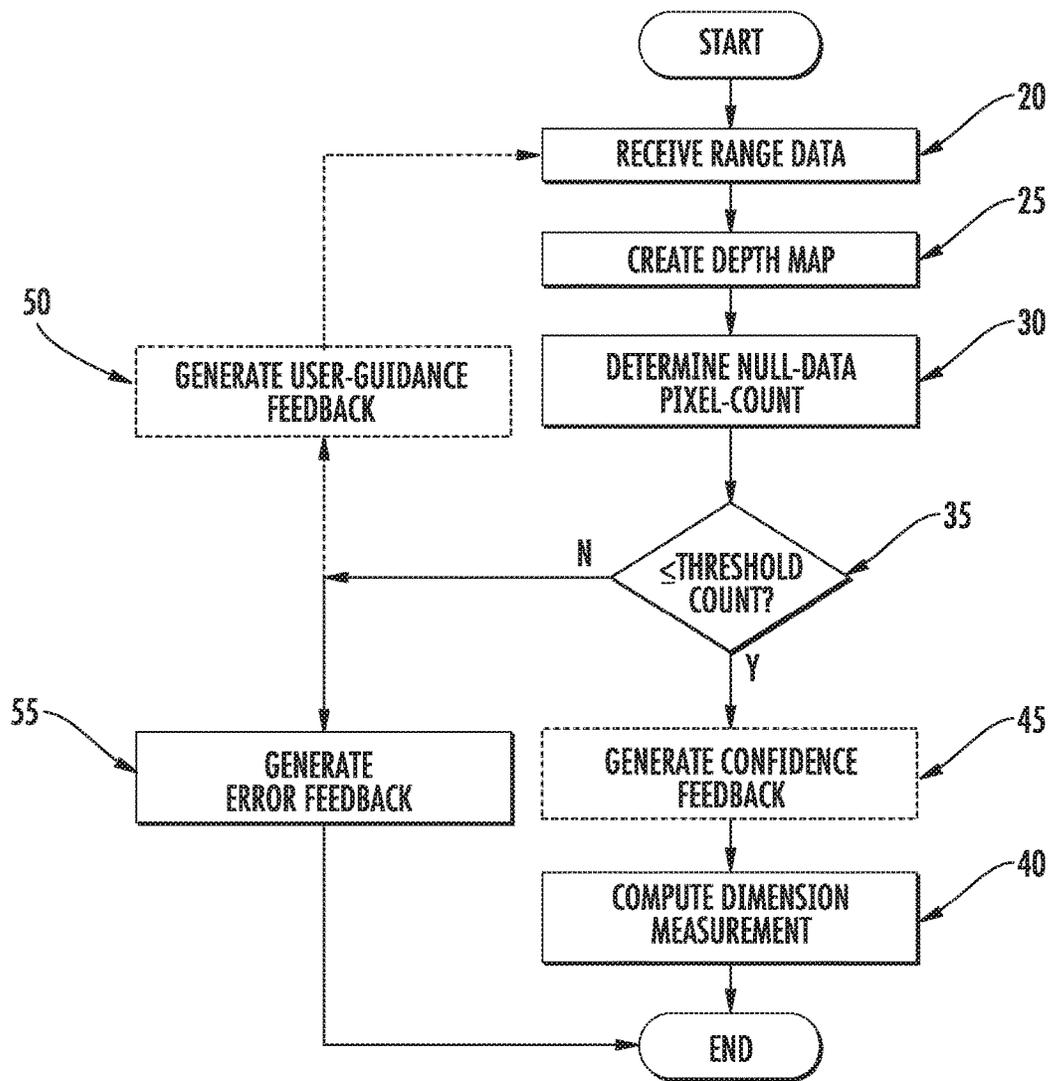


FIG. 4

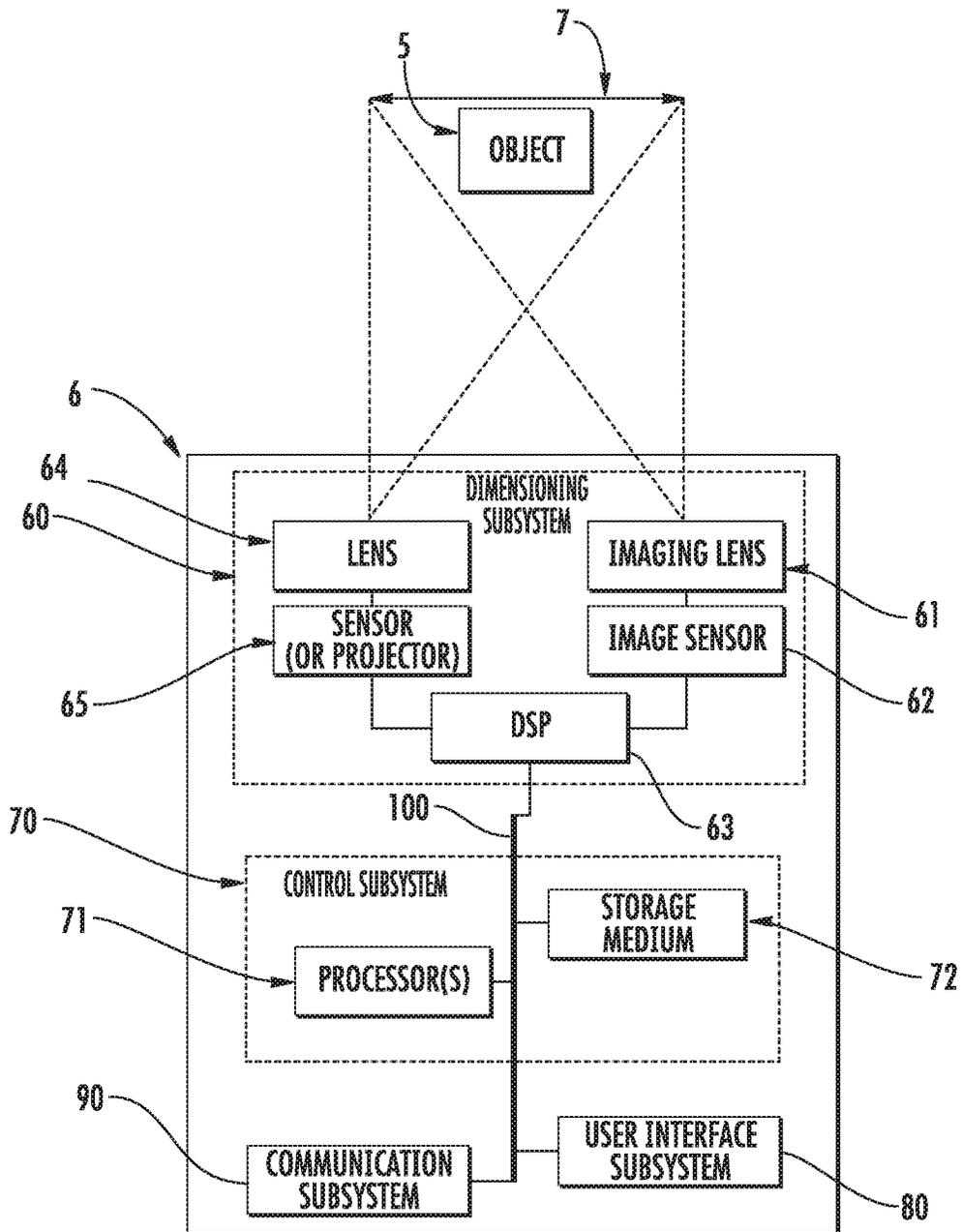


FIG. 5

**DIMENSIONING SYSTEM WITH FEEDBACK****CROSS-REFERENCE TO RELATED APPLICATIONS**

The present application claims the benefit of U.S. patent application Ser. No. 15/581,572 for a Dimensioning System with Feedback filed Apr. 28, 2017 (and published Aug. 10, 2017 as U.S. Patent Publication No. 2017/0230639), now U.S. Pat. No. 9,826,220, which claims the benefit of U.S. patent application Ser. No. 14/519,195 for a Handheld Dimensioning System with Feedback filed Oct. 21, 2014 (and published Apr. 21, 2016 as U.S. Patent Publication No. 2016/0109220), now U.S. Pat. No. 9,638,512. Each of the foregoing patent applications, patent publications, and patents is hereby incorporated by reference in its entirety.

**FIELD OF THE INVENTION**

The present invention relates to dimensioning systems, and in particular, to a dimensioning system that can provide feedback relating to the quality of data used for a dimension measurement.

**BACKGROUND**

Hands-free measurements of an object's dimensions (e.g., volume) may be carried out using a dimensioning system. Dimensioning systems can compute a package's volume to facilitate its storage, handling, transporting, and/or invoicing. Most transport vehicles have both volume and weight capacity limits, and an inefficient use of space results if the transport vehicle becomes full before its weight capacity is reached. By dimensioning packages, shipping companies can fill space optimally and compute shipping charges accurately. For this reason, dimensioning systems that accurately gather volume information, without causing disruptions in workflow, are highly desirable.

Handheld dimensioners require no dedicated setup to measure a dimension. These devices are small (e.g., fit into a user's hand) and convenient since the dimensioner is mobile. The handheld dimensioner can be positioned in a wide variety of environments. These environments may vary considerably because of lighting, object positioning, and/or object coloring. Some environments are not suitable for dimensioning; however, this is not always obvious to a user.

A need, therefore, exists for a handheld dimensioning system configured to (i) analyze the quality of the data used for dimensioning and (ii) provide feedback regarding this data, especially where dimensioning errors might otherwise result.

**SUMMARY**

Accordingly, in one aspect, the present invention embraces a method for obtaining a dimension measurement using a handheld dimensioner. The method includes the step of using a processor to receive range data from a dimensioning subsystem. From the range data, a processor creates a depth map. The depth map is analyzed, using the processor, to determine the depth map's null-data pixel count, wherein the null-data pixel count is the sum total of the null-data pixels. If the null-data pixel count is at or below a threshold count, then the processor computes a dimension measurement. Alternatively, if the null-data pixel-count is above the threshold count, then the processor generates an error feedback.

In an exemplary embodiment, the processor generates a confidence feedback if the depth-map's null-data pixel count is below the threshold count. An exemplary confidence feedback is a visible image of the handheld dimensioner's field-of-view including a wireframe rendering of an object. Another exemplary confidence feedback is a confidence value corresponding to the null-data pixel count. Yet another exemplary confidence feedback indicates that the dimension measurement conforms to a standard.

In another exemplary embodiment, the processor generates a user-guidance feedback if the null-data pixel count is above the threshold count. An exemplary user-guidance feedback is information to facilitate the adjustment of a measurement geometry. Another exemplary user-guidance feedback embodiment is information to facilitate the adjustment of lighting.

In another aspect, the present invention embraces a handheld dimensioning system configured to provide error feedback. The dimensioning system includes a dimensioning subsystem with at least one image sensor for capturing range data of an object or objects within a field-of-view. The dimensioning system also includes a control subsystem communicatively coupled to the at least one image sensor. The control subsystem includes at least one processor and at least one non-transitory storage medium for storing information and processor-executable instructions. The processor-executable instructions configure the processor to perform several functions. The processor is configured to receive range data from the dimensioning subsystem and to create a depth map from the range data. The processor is then configured to process the depth map to obtain a depth-map quality. If the depth-map quality is below a minimum quality threshold, then the processor is configured to generate an error feedback.

In an exemplary embodiment, the depth-map quality includes a sum of the number of pixels in the depth map having insufficient information to determine depth.

In another exemplary embodiment, the handheld dimensioning system includes a pattern projector to project a light pattern onto the object or objects in the field-of-view.

The foregoing illustrative summary, as well as other exemplary objectives and/or advantages of the invention, and the manner in which the same are accomplished, are further explained within the following detailed description and its accompanying drawings.

**BRIEF DESCRIPTION OF THE DRAWINGS**

- FIG. 1 depicts an image of an exemplary depth map.  
 FIG. 2 depicts an exemplary feedback including a visible image of an object and a wireframe rendering of the object.  
 FIG. 3 schematically depicts an exemplary measurement geometry.  
 FIG. 4 schematically depicts a flowchart of an exemplary method for obtaining a dimension measurement using a handheld dimensioner.  
 FIG. 5 schematically depicts an exemplary handheld dimensioning system configured to provide error feedback.

**DETAILED DESCRIPTION**

The present invention embraces a handheld dimensioning system (i.e., dimensioner) that provides feedback regarding the quality of the range data used for dimensioning. This qualitative feedback is especially important in handheld dimensioning.

Handheld dimensioning is a challenging problem. In handheld dimensioning applications, the measurement environment is uncontrolled, and the dimensioner must accommodate a wide range of measurement conditions. These measurement conditions include diverse lighting conditions, measurement geometries (e.g., spatial relationships and orientations), and/or object colors.

Handheld applications typically have a low tolerance for excessive measurement times and/or alignment complexities. A handheld dimensioner must employ robust sensing technologies with quality assurance feedback to achieve reliable measurements in adverse measurement conditions.

A variety of sensing technologies have been employed for dimensioning (e.g., time-of-flight sensing or stereoscopic imaging) to capture range data (i.e., depth data). One exemplary sensing technology, well suited for handheld dimensioners, uses structured light to capture range data. Structured-light dimensioners sense depth by projecting a known light pattern (e.g., dots, grids, bars, stripes, checkerboard, etc.) onto a scene (i.e., field-of-view). A pattern image is captured by an image sensor laterally offset from the projector. Distortions in the reflected light pattern caused by objects in the field-of-view are analyzed to derive depth (i.e., range) information.

A handheld-dimensioner's dimensioning subsystem may use structured light to sample spatially the range between the dimensioning system and an object (or objects) within the field-of-view. These samples combine to form a two-dimensional (2D) array of range data. This range data is used to create a depth map.

A typical depth map is shown in FIG. 1. The depth map 1 is a two-dimensional digital image wherein the pixel values correspond to the sampled range. For the exemplary depth map in FIG. 1, close (i.e., short-range) pixels are lighter, while far (i.e., long range) pixels are darker.

Some pixels in the depth map 1 are black. These black pixels represent null-data pixels 2. Null-data pixels are points in the field-of-view that provided insufficient information to determine depth (i.e., range). Black null-data pixels are shown in the depth map 1; however, any pixel value could represent null-data pixels 2.

A variety of measurement conditions cause null-data pixels. One such condition is lighting. Suitable lighting is necessary to capture images of the light pattern used in structured-light dimensioners. Too little light may lead to noisy images, while excessive light may lead to saturated images. The lighting must also be uniform. Images with dark areas and saturated areas may have null-data pixels in both, since the dynamic range of the image sensor is often too small to capture both ideally.

The depth map 1 in FIG. 1 has null-data pixels 2 along some edges and on the largest object surface shown. FIG. 2 shows visual feedback of the object. The feedback includes a visible image 3 of the object and shows that the source of the null-data pixels 2 is the darkly colored printing 4 on the side of the object. The printing 4 reflects light poorly, leading to a low-light imaging condition. The light pattern (in this area) cannot be imaged to determine range. These pixels are assigned a zero value (i.e., null-data pixels). Object color can cause null-data pixels 2, and is a fact that may not be obvious without evaluating the depth map.

Certain measurement geometries can also lead to null-data pixels 2. Here measurement geometry refers to the measurement setup (e.g., spatial relationships and/or orientations). FIG. 3 depicts an exemplary measurement geometry. An object 5 for dimensioning is placed within a dimensioning system's 6 field-of-view 7. The object 5 is

positioned at a range 8 (i.e., the distance between the dimensioning system and the object). Typically, three sides of the object are visible (to the dimensioner) for volume measurements. A surface 11 is visible when two of its edges 9,10 create an angle 12 (i.e., an angle with respect to the dimensioner's optical axis) that is greater than zero. Larger angles 12 imply more surface visibility. Feedback to facilitate the positioning of an object (or dimensioner) to maximize surface visibility is helpful in obtaining accurate dimensioning results.

When using a structured light dimensioner, an object's side must reflect some minimum portion of the projected light pattern to convey depth information (i.e., range data). For the measurement geometry in FIG. 3, the object 5 can be rotated 13 to adjust the angle 12 so that a surface 11 reflects more of the projected light pattern. Without feedback, it may be difficult to make this adjustment.

Feedback is necessary to quantify the quality of the depth map. The depth-map quality is typically determined by quantifying the number of null-data pixels in the depth map (i.e., null-data pixel-count). For example, the null-data pixel-count is the sum of the null-data pixels in a depth map.

The null-data pixel-count may determine the feedback type. If the null-data pixel-count is above a threshold count, then the processor may generate an error feedback. In another exemplary embodiment, if the ratio of the null-data pixel-count to the total number of pixels for a surface is higher than a threshold (e.g., 10%), then error feedback may be generated. Error feedback may indicate that the depth map is not suitable for dimensioning and could cause a measurement error or inaccuracy.

When the dimensioning system employs a time-of-flight sensor to generate three-dimensional data, the depth map is replaced with a distance map but the functionality is the same. Here each distance-map pixel may be assigned a confidence value. This confidence value may be averaged over the image or over a surface within the image. If the average confidence value over a prescribed area is below a threshold (e.g., 80%) then the processor may generate an error feedback. The error feedback may indicate that the distance map is not suitable for dimensioning and could cause a measurement error or inaccuracy.

Error feedback may include an indication that the handheld dimensioner cannot produce a dimension measurement under the current conditions. Error feedback may also include an indication that at least one object surface is not visible. In another embodiment, the error feedback may include an indication that the object color is too dark or that the lighting is insufficient. In some embodiments user-guidance feedback is provided in addition to (or instead of) error feedback whenever the threshold count is exceeded.

User-guidance feedback provides information to facilitate the adjustment of the measurement setup to improve the depth-map's quality. User-guidance feedback may indicate an adjustment to the measurement geometry (e.g., "rotate object" or "move dimensioner up"). User-guidance feedback may also specify an adjustment to the handheld-dimensioner's settings (e.g., "change shutter speed"). In another exemplary embodiment, the user-guidance feedback may include information to facilitate the adjustment of lighting.

After complying with the user-guidance feedback, a user may take another dimension measurement. A new depth map is then created, evaluated, and compared to the threshold count. This process could repeat until the depth map's null-data pixel count is at, or below, the threshold count. Alternatively, this repetition could end after some fixed number of trials.

If the depth map's null-data pixel-count is at or below the threshold count then the depth-map quality is suitable for dimensioning. The processor uses the depth map to compute a dimension measurement. A confidence feedback may also be generated.

Confidence feedback may include a visible image of the handheld-dimensioner's field-of-view and a wireframe rendering of the object created from range data. This confidence feedback is shown in FIG. 2. In this example, the wireframe rendering 15 matches the object 5, and in this way, helps provide confirmation that the dimensioning measurement is valid.

The confidence feedback could also include a confidence value. The confidence value could, for example, correspond to the percentage of null-data pixels (e.g.,  $[100\% - \text{null-data-pixel}\%] = \text{confidence}\%$ ). Using this approach, a confidence value of 100% is a perfect depth map (i.e., with no null-data pixels), while a confidence value of 0% would represent the worst possible depth map.

In another embodiment, the confidence feedback indicates the dimension measurement's conformance to a standard. Industry standards promote healthy business and consumer climates by providing specifications to insure uniform and equitable measurements. Standards may require a particular measurement accuracy. The confidence feedback could indicate that a dimension measurement meets the requirements stipulated in one or more industry standards.

The feedback types describe so far (i.e., user-guidance feedback, error feedback, or confidence feedback) could each include indications embodied in a variety of forms. Audio or visible messages could convey the feedback. Audio feedback could include sounds or voice commands. Visible feedback could include illuminated indicators and/or graphics/text displayed on a screen.

FIG. 4 illustrates an exemplary a dimensioning measurement method including feedback based on a depth-map quality assessment. A handheld dimensioner is used obtain a dimension measurement. Range data is collected by a dimensioning subsystem that (in one possible embodiment) projects an infrared (IR) light pattern onto an object. The method begins with handheld dimensioner's processor receiving range data from the dimensioning subsystem 20. The processor then creates a depth map from the range data 25. This depth map may have null-data pixels. In the next step, the processor determines a null-data pixel-count 30 (i.e., summates the null-data pixels). The processor then compares the null-data pixel-count to a stored threshold count 35. This threshold count is based on a variety of factors that vary with application. The threshold count may be stored in the handheld dimensioner's memory and may be adjusted to meet the requirements associated with different applications.

If the null-data pixel-count is less than or equal to the threshold count, then the processor may compute a dimension measurement 40. In some embodiments, confidence feedback may be generated 45 and presented separately, or with, the dimension measurement.

If the null-data pixel count is greater than the threshold count, then the processor may (in some embodiments) use information derived from the depth map to generate user-guidance feedback 50. This user-guidance feedback facilitates the adjustment of the dimensioner, the environment, and/or the object for an improved range data acquisition. Acquiring range data, creating a depth map, and comparing the null-data in the depth map to a threshold count may repeat until a depth map with sufficient quality is obtained.

Error feedback may be generated 55 if the null-data pixel count is greater than the threshold count. This error feedback helps to alert the user that the data acquired is not suitable for a dimensioning measurement.

FIG. 5 schematically depicts a block diagram of an exemplary handheld dimensioning system configured to provide error feedback. An object 5 positioned in front of the dimensioning system 6 may have its dimensions (e.g., volume) measured optically. The dimensioner 6 utilizes a variety of subsystems to measure the object.

A dimensioning subsystem 6 uses at least one image sensor to capture range data of an object or objects within a field-of-view 7. To accomplish this, the dimensioning subsystem 60 uses an imaging lens 61 to focus a real image of the field-of-view 7 onto an image sensor 62 to convert the optical image into an electronic signal. The image sensor 62 may be a charge coupled device (i.e., CCD) or a sensor using complementary metal oxide semiconductor (i.e., CMOS) technology. The image sensor 62 typically includes a plurality of pixels that sample the real image and convert the real-image intensity into an electronic signal. A digital signal processor (i.e., DSP) 63 is typically included to facilitate the formation of the digital image.

The creation of range data (i.e., depth information) is facilitated by a second element in the dimensioning subsystem that either transmits an optical signal (i.e., projector) or images a scene (i.e., sensor). The lens 64 for the projector (or sensor) 65 is typically configured into a stereo arrangement with the imaging lens 61 to allow for the collection of depth information (e.g., using the principle of parallax). The projector (or sensor) 65 is typically communicatively coupled to the DSP 63 which may facilitate its control and communication.

A control subsystem 70 is communicatively coupled to the at least one image sensor (or the image sensor 61 and the projector 65) via the DSP 63. The control subsystem 70 includes one or more processors 71 (e.g., one or more controller, digital signal processor (DSP), application specific integrated circuit (ASIC), programmable gate array (PGA), and/or programmable logic controller (PLC)) to configure the imaging subsystem for the dimensioning data collection and to perform the processing to generate dimensioning measurements and feedback. The processor 71 may be configured by processor-executable instructions (e.g., a software program) stored in at least one non-transitory storage medium (i.e., memory) 72 (e.g., read-only memory (ROM), flash memory, and/or a hard-drive). The processor-executable instructions, when executed by the processor 71 configure the processor to: (i) receive range data from the dimensioning subsystem, (ii) create a depth map from the range data, (iii) process the depth map to obtain a depth-map quality, and (iv) generate an error feedback if the depth-map quality is below a minimum-quality threshold.

The dimensioning system 6 may also include a user-interface subsystem 80 to display dimension measurements (e.g., linear dimension or volume) and feedback. In some embodiments, the user-interface subsystem 80 may also facilitate the selection of objects and/or surfaces for dimensioning.

The dimensioner 6 may also include a communication subsystem 90 for transmitting and receiving information to/from a separate computing device or storage device. This communication subsystem 90 may be wired or wireless and may enable communication via a variety of protocols (e.g., IEEE 802.11, including WI-FI®, BLUETOOTH®, CDMA, TDMA, or GSM).

The subsystems in the dimensioner **6** are electrically connected via a couplers (e.g., wires or fibers) to form an interconnection subsystem **100**. The interconnection system **100** may include power buses or lines, data buses, instruction buses, address buses, etc., which allow operation of the subsystems and interaction there between.

To supplement the present disclosure, this application incorporates entirely by reference the following commonly assigned patents, patent application publications, and patent applications:

U.S. Pat. No. 6,832,725; U.S. Pat. No. 7,128,266;  
 U.S. Pat. No. 7,159,783; U.S. Pat. No. 7,413,127;  
 U.S. Pat. No. 7,726,575; U.S. Pat. No. 8,294,969;  
 U.S. Pat. No. 8,317,105; U.S. Pat. No. 8,322,622;  
 U.S. Pat. No. 8,366,005; U.S. Pat. No. 8,371,507;  
 U.S. Pat. No. 8,376,233; U.S. Pat. No. 8,381,979;  
 U.S. Pat. No. 8,390,909; U.S. Pat. No. 8,408,464;  
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 U.S. Pat. No. 8,469,272; U.S. Pat. No. 8,474,712;  
 U.S. Pat. No. 8,479,992; U.S. Pat. No. 8,490,877;  
 U.S. Pat. No. 8,517,271; U.S. Pat. No. 8,523,076;  
 U.S. Pat. No. 8,528,818; U.S. Pat. No. 8,544,737;  
 U.S. Pat. No. 8,548,242; U.S. Pat. No. 8,548,420;  
 U.S. Pat. No. 8,550,335; U.S. Pat. No. 8,550,354;  
 U.S. Pat. No. 8,550,357; U.S. Pat. No. 8,556,174;  
 U.S. Pat. No. 8,556,176; U.S. Pat. No. 8,556,177;  
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 U.S. Pat. No. 8,571,307; U.S. Pat. No. 8,579,200;  
 U.S. Pat. No. 8,583,924; U.S. Pat. No. 8,584,945;  
 U.S. Pat. No. 8,587,595; U.S. Pat. No. 8,587,697;  
 U.S. Pat. No. 8,588,869; U.S. Pat. No. 8,590,789;  
 U.S. Pat. No. 8,596,539; U.S. Pat. No. 8,596,542;  
 U.S. Pat. No. 8,596,543; U.S. Pat. No. 8,599,271;  
 U.S. Pat. No. 8,599,957; U.S. Pat. No. 8,600,158;  
 U.S. Pat. No. 8,600,167; U.S. Pat. No. 8,602,309;  
 U.S. Pat. No. 8,608,053; U.S. Pat. No. 8,608,071;  
 U.S. Pat. No. 8,611,309; U.S. Pat. No. 8,615,487;  
 U.S. Pat. No. 8,616,454; U.S. Pat. No. 8,621,123;  
 U.S. Pat. No. 8,622,303; U.S. Pat. No. 8,628,013;  
 U.S. Pat. No. 8,628,015; U.S. Pat. No. 8,628,016;  
 U.S. Pat. No. 8,629,926; U.S. Pat. No. 8,630,491;  
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 U.S. Pat. No. 8,636,224; U.S. Pat. No. 8,638,806;  
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In the specification and/or figures, typical embodiments of the invention have been disclosed. The present invention is not limited to such exemplary embodiments. The use of the term "and/or" includes any and all combinations of one or more of the associated listed items. The figures are schematic representations and so are not necessarily drawn to scale. Unless otherwise noted, specific terms have been used in a generic and descriptive sense and not for purposes of limitation.

The invention claimed is:

**1.** A method, comprising:  
 receiving, with a processor, range data from a dimensioning subsystem;  
 creating, with the processor, a distance map from the received range data;  
 determining, with the processor, a null-data pixel-count from the distance map, the null-data pixel-count comprising a sum total of null-data pixels; and  
 computing, with the processor, a dimension measurement if the null-data pixel-count is at or below a threshold count, or  
 generating, with the processor, an error feedback if the null-data pixel-count is above the threshold count.  
**2.** The method according to claim **1**, wherein the distance map comprises a digital image of a dimensioner's field-of-view, wherein the digital-image's pixel values correspond to the distance between the dimensioner and an object or objects in the field-of-view.

**3.** The method according to claim **2**, wherein the distance map's null-data pixels comprise a single pixel value, the single pixel value indicating that a range measurement for a pixel was not possible.

**4.** The method according to claim **1**, comprising generating a confidence feedback if the distance map's null-data pixel-count is below the threshold count.

**5.** The method according to claim **4**, wherein the confidence feedback comprises a visible image of a dimensioner's field-of-view and a wireframe rendering of an object, the wireframe rendering displayed with the visible image.

**6.** The method according to claim **4**, wherein the confidence feedback comprises an indication of a confidence value, the confidence value corresponding to the null-data pixel count.

**7.** The method according to claim **4**, wherein the confidence feedback comprises an indication of the dimension measurement's conformance to a standard.

**8.** The method according to claim **1**, comprising generating a user-guidance feedback if the null-data pixel-count is above the threshold count.

**9.** The method according to claim **8**, wherein the user-guidance feedback comprises information to facilitate the adjustment of a measurement geometry.

**10.** The method according to claim **8**, wherein the user-guidance feedback comprises information to facilitate the adjustment of lighting.

**11.** The method according to claim **8**, comprising repeating the receiving, creating, determining, and generating until the distance map's null-data pixel-count is at or below the threshold count then computing a dimension measurement.

**12.** The method according to claim **1**, wherein the error feedback comprises audio feedback.

**13.** The method according to claim **1**, wherein the error feedback comprises illuminated indicators and/or graphics displayed by the dimensioner.

**14.** The method according to claim **1**, wherein the error feedback comprises an indication that the object color is too dark or that the lighting is insufficient.

**15.** A system, comprising:

a dimensioning subsystem comprising at least one image sensor for capturing range data of an object or objects within a field-of-view; and

a processor communicatively coupled to the at least one image sensor, wherein the processor is configured to: receive range data from the dimensioning subsystem; create a distance map from the range data; process the distance map to obtain a distance-map quality comprising a sum of the number of pixels in the distance map having insufficient information to determine distance; and generate an error feedback if the distance-map quality is below a minimum-quality threshold.

**16.** The system according to claim **15**, wherein the dimensioning subsystem comprises a pattern projector, the pattern projector projecting a light pattern on the object or objects in the field-of-view.

**17.** The system according to claim **15**, wherein the error feedback comprises user guidance information to facilitate the repositioning of the dimensioner to capture range data having an improved distance-map quality.

**18.** The system according to claim **15**, comprising a user-interface subsystem for displaying dimension measurements and the error feedback.

19. The system according to claim 15, comprising a communication subsystem for transmitting and receiving information to/from a computing device and/or a storage device.

20. The system according to claim 15, comprising a display for displaying dimension measurements and the error feedback.

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